The SIRTF in-orbit checkout and science verification plan

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ABSTRACT

The Space Infrared Telescope Facility (SIRTF) observatory is an 85-cm telescope with three cryogenically cooled instruments. Following launch, the observatory will be initialized and commissioned for routine operations during a sixty-day period called In-Orbit Checkout (IOC), and a subsequent thirty-day period called Science Verification (SV). The emphasis for the IOC phase is to bring the observatory on-line safety and expeditiously, verify functionality of the instruments, telescope, and spacecraft, and demonstrate that the facility meets level-1 requirements. The emphasis of the SV phase is to characterize the observatory in-orbit performance, demonstrate capability for autonomous operations, conduct early release observations, and exercise the ground systems software, processes, and staffing sufficiently to commission the facility for routine operations.

The design of the IOC/SV phases is dominated by two unique features of the SIRTF mission: the solar orbit that affects the thermal design and the communications strategy, and the warm launch architecture whereby the telescope is outside the cryostat and radiatively cools in deep space. The key challenges of SIRTF are in the areas of optical, cryogenic, and pointing control performance, which have dependencies on the performance of the three instruments, and vice versa. In addition, the mission and science operations teams must face the challenge of operating a new space observatory and safely establishing autonomous operations in a very short time. This paper describes a nominal mission plan that progressively establishes SIRTF capabilities during the IOC/SV phases, taking into consideration thermal, cryogenic, optical, communications, celestial mechanics, and operational designs and constraints.

Keywords: SIRTF, IOC, calibration, checkout, operations

1. INTRODUCTION

The Space Infrared Telescope Facility (SIRTF) will provide unprecedented sensitivity to explore the birth and evolution of the universe. It makes use of some of the nation's premier technologies in fundamental scientific applications such as the discovery and study of protoplanetary and planetary debris disks, the study of ultraluminous galaxies and active galactic nuclei, the study of the early universe, and the search and study of brown dwarfs and super planets.

The observatory will be injected by a Delta 7920H launch vehicle into an escape trajectory, resulting in a heliocentric orbit in which the observatory moves around the Sun in roughly the same orbit as the Earth, with the observatory slowly drifting away from the Earth at an average rate of 0.12 AU/year. This orbit eliminates heat input from the Earth, allowing the unique cryogenic design that achieves a mission lifetime of at least 2.5 years and possibly 5 years using 335 liters of superfluid helium. The cold instrument power dissipation is less than 8 mW, the detector bath temperature is 1.4 K, the telescope temperature is 5.5 K, and the outer shell temperature is about 35 K–40 K. The solar orbit also eliminates the need for station-keeping and provides a more efficient observing environment.

The observatory consists of the Cryo-Telescope Assembly (CTA), the Spacecraft (S/C), and three science instruments (SIs): the Infrared Array Camera (IRAC), the Infrared Spectrograph (IRS), and the Multiband Imaging Photometer for SIRTF (MIPS). The three SIs each consist of a cold assembly mounted in the cryostat and warm electronics mounted in the S/C bus. The CTA consists of an outer shell that radiates to cold space in the anti-Sun direction, and is shielded from the Sun by the solar panel assembly. The CTA outer shell surrounds a series of thermal shields, the telescope, the cryostat, and the cold instruments. The S/C bus contains the subsystems required for housekeeping and control engineering: telecommunications, reaction control, pointing control, command and data handling, power, and fault protection.

Unlike the conventional cold launch architecture in which the telescope, science instruments, and superfluid liquid helium tank are surrounded with a vacuum shell, SIRTF implements a warm launch architecture in which the vacuum shell surrounds only the instrument chamber and the helium tank. The warm launch cryogenic system enables significant size and mass reduction through a smaller vacuum chamber and lower cryogen consumption. The cryogen consumption is dominated by the heat dissipation of the SI cold assemblies, because most of the parasitic heat input is intercepted by the cooling power of the effluent helium vapor by thermally connecting the helium vent line to key cryostat components. The telescope is attached to the top of the vapor cooled cryostat vacuum shell. The telescope is launched warm, and cools down on orbit over a period of 45 days to its operating temperature of 5.5 K.

The in-orbit checkout and science verification mission plan sets forth the activities and guidelines needed to commission SIRTF for routine operations. The plan is divided into two phases, in-orbit checkout (IOC) and science verification (SV). The emphasis for the IOC phase is to bring the facility on-line safely and expeditiously, verify the functionality of the instruments, telescope, and spacecraft, and demonstrate that the facility meets level 1 requirements. The emphasis for the SV phase is to characterize the observatory in-orbit performance, demonstrate observatory capability for autonomous operations, conduct early release observations, and exercise the ground systems software, processes, and staffing sufficiently to commission the facility for routine operations. The IOC phase is to be completed within 60 days after launch, and the SV phase completed within 90 days after launch.

The IOC/SV plan is provided to the observatory and ground segment for implementation. The timeline provided with the plan is not intended as a fixed schedule, but as a guideline for the observatory and Ground Segment to develop the capabilities necessary to implement the timeline. Past missions have shown that the value of a mission plan is the communication among the development and operations teams on how the mission is to progress after launch, and the preparation of the development and operations teams to execute the mission plan. The SIRTF teams must be flexible to respond to anomalies that will require them to deviate from the plan.

Section 2 contains an overview of the IOC planning process and the resulting timeline. Section 3 contains descriptions of all of the IOC and SV activities. Section 4 enumerates the assumptions and rules governing the IOC/SV plan. Section 5 lists all the identified tools needed to plan/execute IOC/SV. Section 6 is a requirements compliance matrix which shows how the requirements in the IOCRD are traced to activities in the IOC/SV plan.

2. OPERATIONS CONCEPT

Operating conditions during IOC and SV are expected to be intense compared to nominal operations. IOC/SV operations differ from nominal operations in several aspects. The operations team will include the nominal operations team and observatory development personnel. The IOC/SV operations team must be able to function rapidly to make adjustments to the IOC/SV plan as necessary. Near continuous coverage of the observatory by the deep space network (DSN) and the mission operations system will be provided. The mode of operation is continually evolving, i.e., the telescope temperature is changing and the PCS performance is improving. Critical decisions must be made, especially the focus adjustment.

3. PLANNING PROCESS

The plan was developed by the IOC integrated product team (IPT). The team identified all of the required IOC/SV activities, estimated the duration of each activity and placed these activities end-to-end on a timeline making certain that the timeline satisfied the various constraint conditions. The order of activities was determined by:

- A "walk-before-you-run" logic since basic functions need to be verified before more complicated modes can be tested or more detailed calibrations performed.

- The telescope temperature that determines the earliest time that a particular observation can take place given the background noise at a particular wavelength.

- The level of pointing accuracy/stability required to place and hold a target on the science aperture or otherwise to perform a specific test.

- Whether the test requires the telescope to be in focus.
- The need for and the availability of real-time data downlink.
- The need in certain cases for dual DSN station coverage.
- The need in some cases to analyze the results of one activity and modify the subsequent sequences (if necessary) before proceeding with the next activity in a set.
- The necessity of operating only one instrument at a time.
- The continuing need to perform routine functions such as pointing calibrations, reaction wheel momentum dumps, data downlink, command uplink, etc.
- Mitigate risk by executing trial runs of complex activities early in IOC, when the timeline is not fully subscribed, to increase the likelihood that surprises will be discovered sooner rather than later.

Many solutions exist which satisfy all the constraints. Additional tests or refinements in the activity strategy and/or scheduling procedure are expected to emerge. On-orbit, unexpected events or results will alter the actual sequence of activities executed, and real-time replanning will necessarily be a part of the operations process.

3.1 Principals

Each activity has a designated principal. Principals are responsible for the overall design, implementation, and execution of an activity. Principals lead activity planning and strategy definition, define success criteria, identify constraints, interfaces, and tools, identify required ground tests and data products, review uplink and downlink products, and lead data analysis efforts and reporting. Principals have the responsibility to see that sequences are designed, test plans and procedures are developed, and operations procedures are written. Principals may need to be part of the test teams, participate in demonstrations and rehearsals, get trained in operations, and support other principals.

3.2 Activity Database

Each IOC/SV activity is documented in the IOC Activity Database. The database contains all the key information about each activity. Everyone on the Project has browse access; only principals have permission to create and edit activities. The principals are responsible for keeping information in the database complete, accurate, and up-to-date. The web-based interface allows formatted tracking of activity information through the use of standard input forms (templates). Pop-up menus, radio buttons, and help text on the input form help standardize field entries where appropriate. Every change is stored as a new version of the activity record, and all old versions are maintained, so a complete historical record of the database content is always available. Summary reports in Excel spreadsheet format can be automatically generated.

3.3 Constraints

In general, activities are scheduled as early as their constraint conditions allow.

3.3.1 Telescope Cooldown

During the cooldown, activities are scheduled as soon as their temperature constraint allows, unless driven by another constraint.

3.3.2 Rules Of Precedence

Many activities depend on the results of previous activities, and these rules of precedence are tracked so that when changes are required, they are made without violating the rules.

adjustment has 15.91 days worth of activities planned, leaving 20.04 days for contingency time and reserve time. The period of IOC after focus adjustment has 19.00 days of activities planned, leaving 3.43 days for contingency and reserve. The SV period has 27.04 days worth of activities planned, leaving 2.96 days for contingency and reserve. All activities include 10%-20% margin. Highlights of the timeline are shown in Figure 2-2.

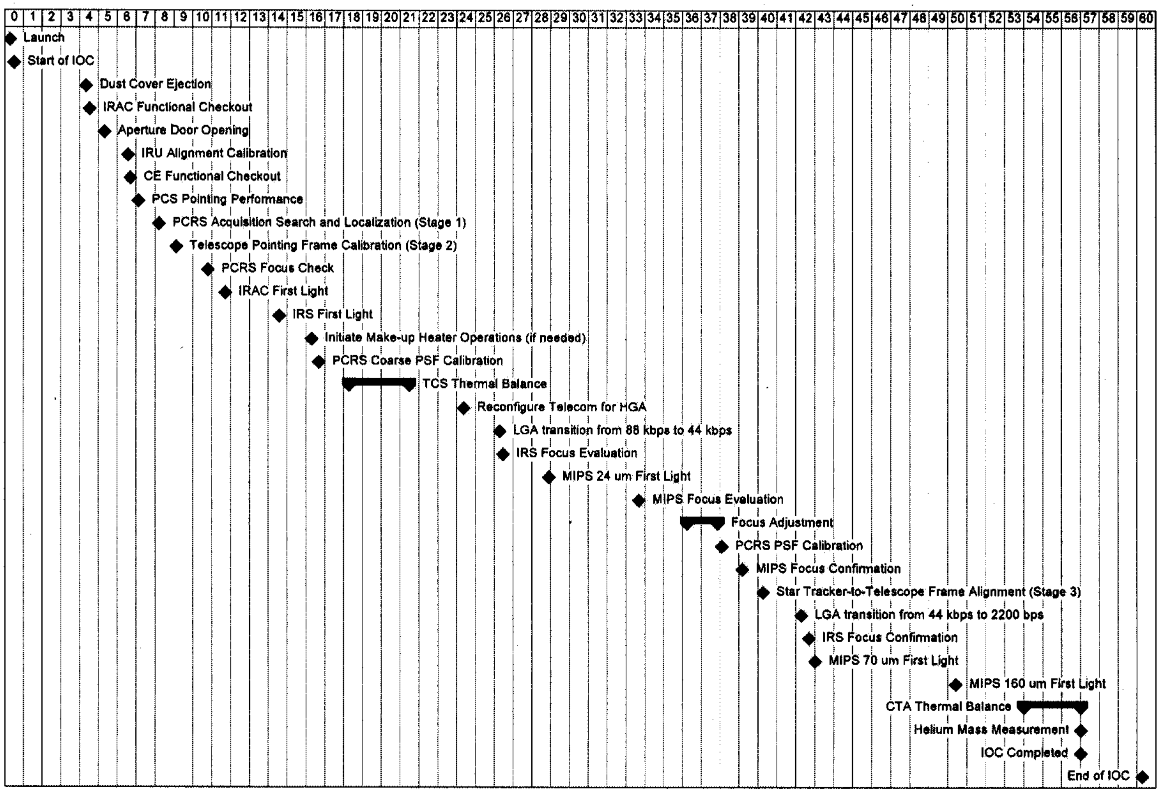

Figure 2-2: IOC timeline highlights

4.2 Launch and Ascent

The observatory is scheduled to be launched on 9 January 2003 by a Delta II 7920H on a direct ascent trajectory. During ascent and after fairing separation, cryostat vent line valves are programmed to autonomously open to allow cryostat venting and to begin telescope cooldown. The valves must be opened under acceleration to ensure helium does not flood past the porous plug into the vent line preventing setup of phase separation (resulting in reduced helium lifetime). After the observatory separates from the launch vehicle second stage, it is programmed to achieve a sun safe attitude. Both the vent valve activity and the attitude initialization take place outside of contact with the ground. Once telecommunications have been established, the first responsibility of the ground team is to confirm that these critical events have occurred and to immediately send commands to perform these functions if telemetry indicates that the desired states have not been achieved.

After these states have been confirmed, the telemetry is monitored and a system status poll is taken to assure that all subsystems are nominal and all parameters are within specified ranges. On successful completion of the status poll, the mission phase discriminator bits are set to flight by ground command. These bits survive a reset or a side swap, so that the observatory always comes up in the proper mode. This milestone constitutes the end of the launch phase, and the beginning of IOC.

4.3 Initial Reconfiguration and Checkout

The first IOC activity is to perform a limited verification of the CTA health and status by reviewing CTA telemetry. Second, post-launch reconfiguration and initial checkout of the pointing control subsystem (PCS) is performed before more intense activities are carried out. This checkout assesses attitude control functions and attitude reference modes, verifies measurement consistency between the star tracker (STA), wide-angle sun sensor (WASS), ephemeris, and inertial reference unit (IRU) during slews, and estimates the relative alignment between the WASS and STA.

A momentum management checkout confirms the functionality of the thrusters and reaction wheel assemblies (RWAs) and tests the various PCS momentum management modes, periodically used to remove some or all of the momentum accumulated in the system to keep the reaction wheels (RWAs) within their operating speed range.

Once the observatory is safely outside the lunar orbit, about 2 days after launch, star tracker calibrations are executed. The first Sun/Earth ephemeris file update, based on flight tracking data, is uploaded at L + 2 days. The initial pointing calibration and reference sensor (PCRS) checkout event is performed prior to the dust cover ejection so that the system noise performance can be measured in true darkness without sky background contributions. The instrument is powered on for the first time, and images are taken in the dark with an assortment of exposure parameters.

Throughout the entire mission, but with a heightened degree of activity during IOC, the observatory Engineering Team (OET) will monitor the telemetry, compare to model predictions, and update the models as needed. Momentum dumps are expected every other day during the nominal mission but during the first few days after launch the vigorous boil-off from the helium tank will cause more frequent dumps.

4.4 Venting Characterization Tests

Five venting characterization tests are performed to allow the JPL navigation team to characterized the observatory helium venting behavior. The helium is vented through two opposing ports to minimize thrust. The activity consists of collecting Doppler data for 4 hours while pointing one port toward the Earth, then rotating the observatory 180° to point the other port to Earth, and collecting another 4 hours of tracking data. The test is executed at L+ 1.7 days, 5.2 days, 10.8 days, 22.6 days, and 35.6 days, to track the venting acceleration from vigorous boil-off through steady state.

4.5 Dust Cover Ejection

At L + 4.7 days, after the observatory contamination cloud has dispersed to sufficiently low levels, the telescope dust cover is ejected to enhance the passive cooldown of the telescope and to allow any trapped water vapor to escape before it freezes out onto the barrel baffle or telescope optics. During dust cover ejection, the pointing system maintains an observatory attitude that prevents sunlight from entering the telescope. The dust cover ejection mechanism consists of a paraffin actuator, that when heated, releases the spring-loaded cover. Release is confirmed on-board using gyro and reaction wheel data, and the heater is autonomously turned off.

4.6 WASS Calibration, Star Tracker Stray Light, and Solar Array Performance Checkout

After the dust cover ejection, a series of maneuvers are performed to place the sun at various locations covering nearly the full range of the OPZ. Data collected will be used to calibrate the WASS, check for stray light in the star tracker, and evaluate the electrical power subsystem performance including solar array current, voltage, temperature, and utilization over the OPZ range.

4.7 Aperture Door Opening

At L + 5.7 days, the aperture door is opened, which allows photons to reach the focal plane. The aperture door provides a hermetic seal while the telescope and cryostat vacuum shell are warm to protect instruments from contamination during ground operations and launch. The aperture door must be opened after ejection of the dust cover, otherwise trapped water will preferentially seek out the cold cryostat/focal plane. Opening must wait until the telescope has cooled to < 195 K, to ensure no water will outgas from the paint and go into the aperture, but must occur before the aperture door mechanism becomes too cold to operate reliably at < 105 K. The aperture door remains open for the duration of the mission.

4.8 PCRS First Light and SI Functional Checkout

Functional tests include aliveness tests of warm electronics, tests of command and data paths to S/C, array readout and controller function, temperature control, internal calibration lamp tests, and detector response to internal and external sources.

4.9 PCS Checkout Activities

The IRU alignment calibration activity calibrates the IRU misalignment, scale factor, and rate bias. It consists of a repeating series of attitude maneuver profiles in pitch, roll, and yaw, performed with the on-board gyro calibration filter enabled. To estimate the gyro rate bias in the IRU high rate mode, the IRU is commanded to remain in high rate mode, a 600 s inertial hold is executed, and gyro telemetry and the observer estimate of the high rate mode bias is downlinked for ground processing. Then a new configuration file is uplinked with the updated high rate mode bias.

The mass properties measurement updates the estimate of the observatory inertia matrix. A short slew is performed about each of the 3 axes. Ground post-processes attitude quaternions, wheel speeds, and IRU rates to determine the inertia matrix. The updated inertia matrix is then uplinked to the observatory.

The PCS pointing performance activity verifies PCS performance and control. It verifies observer modes and transitions, and the performance of command generator and command sequences, including slews, offsets, scans, point-to-point maneuvers, solar system object tracking, the slew completion indicator flag, the pointing ready indicator flag, and the relative slew completion indicator flag. It demonstrates proper operation of dither patterns.

The PCS settling time characterization determines slew efficiency and validates the settling time model, with the ultimate goal of streamlining science observations. This characterization is performed by executing a series of typical science slews at different sky locations. Data collected during the settling are analyzed to determine settling time statistics.

4.10 Telescope Pointing Frame Definition

The telescope pointing frame (TPF) is defined by the PCRS arrays as shown in Figure 3-7. To measure the TPF, we must find the PCRS detector boresights relative to the star tracker, and determine star tracker-to-PCRS alignment. The TPF measurement strategy begins with PCRS acquisition search and localization, and then a series of telescope pointing frame calibration measurements to achieve the ultimate star tracker-to-telescope frame alignment accuracy.

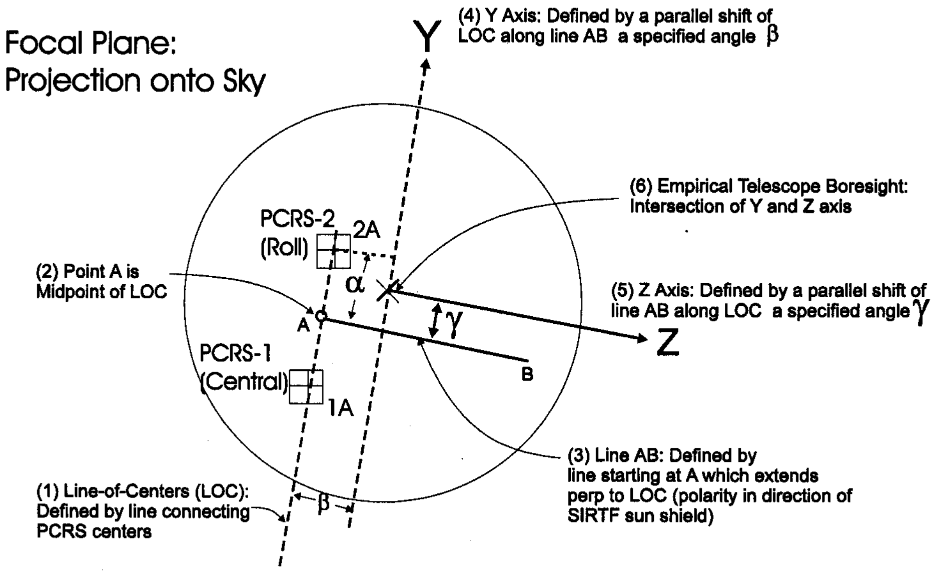

Figure 3-7: Telescope pointing frame defined in terms of the PCRS locations

The PCRS acquisition search & localization (Stage 1) activity locates PCRS-1 and PCRS-2 boresights relative to the star tracker. It generates an initial estimate of star tracker-to-telescope frame using a raster scan to find a specific acquisition star in PCRS-1, and then a mosaic search to find the same star in PCRS-2. Refined estimates of the boresights and frame alignment are derived by placing 80 different stars on each detector, then ground processing the data. This activity produces boresight knowledge to 1 arcsec, and frame alignment knowledge to 1 arcsec pitch and yaw, 100 arcsec roll.

4.11 HGA Switchover

The high gain antenna (HGA) may not be available during the first several days of IOC due to OPZ pointing constraints and the early Sun-observatory-Earth geometry. Instead, data must be returned via the low gain antenna (LGA) which has a much broader antenna pattern. The data rate capability on the LGA is 88 kbps, up until day 25, when the range to earth forces a drop to 44 kbps. If the transition to the HGA has not been completed by day 45, the LGA rate must be further reduced from 44 kbps down to 2200 bps. Once available, the HGA provides a 2.2 Mbps downlink rate capability for the remainder of IOC. The time when the HGA becomes available is nominally day 10, however, it is strongly dependent on launch date. To make the plan robust to launch slips, the switchover to the HGA is planned on day 24.

4.12 Telescope Cooldown

The IOC plan assumes the nominal predicted cooldown of the telescope, which passively reaches its operating temperature of 5.5 K at L + 45 days. At L + 16 days or anytime thereafter (when the telescope cooldown is no longer dominated by radiation and parasitic heat loads, but rather by cryostat power dissipation), if the telescope is cooling more slowly than predicted, the cryostat make-up heater (up to 60 mW) may be turned on to accelerate the boiloff of helium so that the telescope reaches operating temperature by day 45. Once the telescope reaches 5.5 K, the cryostat make-up heat is applied as needed to keep telescope temperature less than 5.5 K for the duration of IOC and SV.

As the telescope cools and the infrared background noise diminishes, observations become possible at longer wavelengths and each of the three science instruments (IRAC, IRS, and MIPS) performs its unique set of tests. Some activities can be carried out with a warm telescope, including initial functional checks to demonstrate that the instrument has survived launch, and warm background monitoring. As each instrument approaches its operating temperature, first light observations are executed. After reaching stable operating temperature, each SI carries out its set of detailed characterizations.

4.13 S/C Thermal Balance

Three 24-hour S/C thermal balance tests are scheduled on days 18-21, after the CTA outer shell has cooled down to operational steady state temperature. For each test, the observatory is set in a different thermal configuration (electrical power and solar angle) for 24 hours to achieve steady state, and thermal data are collected. These data are used to calibrate and validate the S/C thermal model. Observatory temperature readings are monitored throughout IOC period. Heater auto mode operations are monitored to verify that heaters turn on and off properly.

4.14 Focus Adjustment

The focus adjustment activity is scheduled on days 36-37. The decision on the focus adjustment is made taking into account observations from all three instruments. IRAC focus checks are made starting at day 11 and every 2 days thereafter. An IRS focus check with the Short-Low module is made on day 26, the PCRS focus check is on day 10, and the MIPS 24 μm focus check is on day 33. A minimum of 1.5 days are needed between the MIPS focus check and the focus adjustment activity to allow for the data analysis, negotiation/recommendation, and approval process to take place; the current timeline allows 2.5 days. During the focus adjustment activity, IRAC observations are taken immediately prior to and after each focus move to assure that the move occurred as expected. The timeline is planned assuming three moves will be needed. After adjustment, focus confirmation observations are made by PCRS on day 39, IRS on day 42, and MIPS on day 39.

After focus adjustment, IOC and SV are dominated by SI activities. This period is divided into instrument campaigns lasting from 12 hours up to three days. This approach limits the number of instrument-to-instrument transitions (reducing the inefficiencies from the latency time required for the SI warm electronics to reach thermal stability after each transition) and consolidates the time that any particular science team is on real-time duty.

4.15 CTA Thermal Balance and Helium Mass Measurement

On day 57, a 3-day CTA thermal balance test is executed. The CTA cryogenic thermal model must be correlated to flight performance by recording temperature data and updating model parameters. A correlated thermal model improves prediction of telescope temperature for a given helium flow rate and spacecraft temperature. A valid test requires a stable thermal soak for 3 days to achieve steady state. Temperature data are collected and used to calibrate and validate the cryogenic thermal model.

Finally, on day 60, the helium mass measurement is made. The cryostat heater is turned on with precise power and duration. The resultant increase in helium bath temperature is recorded and used to determine helium mass.

Combined with the validated thermal model and assumptions about how helium resources may be conserved by allowing the telescope operating temperature to rise during IRAC and IRS operations, the helium mass yields a prediction of cryogenic lifetime.

4.16 HGA Boresight Calibration

The HGA boresight calibration measures HGA boresight alignment with respect to the S/C and the star tracker, so that the HGA can be pointed accurately to Earth. This activity requires real-time downlink. The ground commands the S/C to small attitude offsets relative to nominal HGA boresight. The ground correlates HGA antenna signals to attitude offsets to assess boresight alignment with respect to commanded attitude.

4.17 Ground System Checkout

The capabilities of the ground system need to be demonstrated during IOC and SV. This includes demonstrations of sustained autonomous operations and pipeline data processing capabilities as well as investigations into optimal observing strategies. No additional activities have been planned to demonstrate these functions, but instead it is assumed that these demonstrations will take place in conjunction with existing activities. For example, autonomous operations can be demonstrated late in the IOC/SV period by executing an n-day science campaign using a single on-board sequence.

4.18 Early Release Observations

Two types of observations to be made during IOC will be available for early release: early characterization observations (ECOs), for SIRTF users, and early release observations (EROs), for the general public.

ECOs consist of data gathered to validate instrument and AOT performance, i.e., no special observations will be planned to produce ECOs. ECOs are therefore the responsibility of SSC and the instrument teams. The goal is to release small amounts of representative ECO data to SIRTF users before the Cycle 1 proposal due date, around L+5 months. ECOs will be released as FITS files produced by the pipeline. In addition, the observing time estimators used in the on-line tools at the SSC will have to be updated well in advance of the proposal due date.

EROs will be conducted during IOC to assure early release to the public and the scientific community of images and spectra demonstrating the capabilities of SIRTF. Nominations will be solicited from the entire SIRTF science community with the targets selected for both their scientific interest and their visual appeal. The final list, including backups and contingencies, will be selected with the concurrence of NASA headquarters. Data will be released within one month of completion of IOC/SV in a non-quantitative format such as JPEG. A total of 24 hours are allocated for EROs, 8 hours for each SI.

4.19 Routine Activities

A periodic IRU alignment update is performed every 24 h ± 2 h to maintain IRU calibration.

The periodic PCRS-to-star tracker alignment filter update maintains knowledge of the star tracker-to-telescope frame alignment in the presence of thermal and mechanical drift. With a star on one of the PCRS detectors, the on-board alignment filter updates the star tracker-to-telescope alignment estimate. PCRS-to-star tracker calibrations are scheduled every 8 hours ± 2 hours.

The on-board ephemeris file is updated every 2 weeks throughout IOC.

HGA downlinks are allocated at least every 6 h during IOC, and at the end of every campaign. Uplink is assumed to occur during downlink. Reaction wheel momentum dumps are routinely enabled during downlinks.

4.20 PCRS Activity Summary

A series of activities are executed soon after focus adjustment to provide photometric calibration, PSF calibration, focus assessment, stray light checks, and accuracy.

4.21 IRAC Activity Summary

4.21.1 Image Quality

Image quality activities include focus assessment and PSF measurement over the fields of view. Optical geometry characterizations are performed to measure distortion, rotation, plate scale, array-to-array alignment, and relative alignment with other SI and PCRS fields of view. Optical performance characterizations include scattered light tests, total system throughput measurements, and flat field measurements.

4.21.2 Detector Characterization

Array characterization activities include determination of final integration times, Fowler N values, and noise properties. A linearity correction measurement is performed. There is a cosmic ray performance activity to evaluate environment and detection algorithms. The anneal function and its effectiveness is assessed. Residual image, bright source effects, and saturation levels are evaluated.

4.21.3 Radiometry

Astronomical calibrators are observed and selected from a list derived from ground-based observations. Observations of stars and extended emission are made to provide absolute calibration in each band. Flat field and dark frame images are taken for each selectable integration time. Cross-instrument calibration objects are selected, and observed from the ground. Internal sources are calibrated with respect to external calibrators, and their stability is characterized. Cool and hot astronomical sources are observed to check for filter leaks and color corrections. Field-dependent wavelength effects are checked.

4.21.4 AOT Commissioning

A series of AOT commissioning activities are planned to verify AOT functionality. All map modes are checked, including full and sub-array, dither patterns, and solar system object tracking. Final parameters for AOTs are determined, including integration times, telescope offset modes and times, time for S/C to ingest and compress IRAC frames, etc. Sky backgrounds are measured with a range of ecliptic latitudes and galactic latitudes and longitudes. Confusion levels are measured with long exposures.

4.22 IRS Activity Summary

4.22.1 Image Quality

The IRS focus is evaluated using the Short-Low module. First, a focus preparation activity is performed, at $T < 60$ K, executing a search pattern to find the Short-Low slit. Then, after $T < 50$ K, slit scans on the Short-Low slit are executed. These scans are analyzed on the ground to determine the IRS focus. After the focus adjustment has been made, the slit scans are repeated to confirm proper IRS focus.

4.22.2 Detector Characterization

Cold aliveness tests are performed to verify functionality such as nominal bias, detector temperature, and stimulator flashes. Dark current and read noise performance as a function of bias and detector temperature is measured. Responsivity and detective quantum efficiency as a function of bias, detector temperature, and stimulator flash settings is measured.

Annealing response and effectiveness is determined by taking RAW and SRS images on all arrays before and after annealing. Start-up transient behavior is characterized by taking RAW images on all arrays during instrument warm-up, to determine the minimum required warm-up period.

4.22.3 Peak-Up
A series of activities are planned to characterize the performance of the Peak-Up mode. Flat field images are obtained and the photometric response is measured for both peakup arrays. Stray light tests are performed using sources scanned outside the Peak-Up field of view. The centroiding performance is characterized by measuring the Peak-Up PSFs and determining centroiding accuracies. The offsetting performance is characterized by measuring small maneuver offset accuracies and photometric slit placement repeatability. Finally, Peak-Up performance is tested while tracking solar system targets.

4.22.4 Wavelength Calibration
A wavelength calibration activity is performed and dispersion coefficients for all modules are determined. Flat field and fringing are characterized via point and extended source observations. Spectro-photometric flux calibration is determined by observing calibrated sources. IRS cross calibrator targets are observed to bootstrap calibration for all 3 instruments. A spectral stray light experiment is performed to determine the effects of off-slit point sources. The point source is scanned in half pixel steps across and in the vicinity of each slit. Long exposure photometric response is characterized to obtain noise vs. integration time for each slit. A test for short wavelength filter leaks is performed by observing a very blue source.

4.22.5 AOT Commissioning
The staring mode AOT and permitted exposure times are validated for all modules. The peak-up imaging AOT and spectral mapping mode AOT are validated for proper operation of AOT/IER sequences.

4.22.6 Campaigns
Early ($T > 32$ K) campaign groupings are dictated by warm baffle observations and common temperature requirements. Later campaigns are longer primarily for reasons of efficiency, i.e., reducing startup and overhead times, rationalizing required dark frames, etc. Campaigns cannot generally be interchanged, since knowledge is built up progressively, e.g., detector performance, then focus and focal plane mapping, then peak-up characterization and calibration, followed by wavelength and photometric calibration, AOT validation, and EROs.

4.23 MIPS Activity Summary

4.23.1 Optimize Operating Parameters
The operating temperature for the 24 μm array is optimized. Ge:Ga focal plane array anneal frequency and type are determined. The bias voltage settings for all detectors are set. Exposure times are selected.

4.23.2 Instrument and In-flight Environment Characterization
Latent image and saturated source behavior are characterized. Detector behavior as a function of sky background is evaluated. Cosmic ray limits on integration times are determined. Off-axis glints and scattered light tests are performed. Point spread functions, basic array geometry, and SED mode slit profile are measured. The Confusion limit is determined. Read noise and dark current levels and stability are characterized. Electronic non-linearity is evaluated.

4.23.3 AOT Commissioning
Initially, basic commanding is exercised to demonstrate AOT functionality. Then, detailed validation is carried out over a wide range of parameter space. Finally, pipeline functionality and quality are demonstrated by performing engineering characterization observations of several types of celestial sources.

MIPS has four science operating modes: photometry & super resolution imaging (Ph/SR), freeze-frame scan-mapping (Scan), spectral energy distribution (SED), and total power measurement (TP). Ph/SR, Scan, and SED AOTs have been selected to be available for Cycle 1 observing. Ph/SR and Scan will undergo full operational IOC testing, validation, optimization, and characterization during IOC. SED will be fully validated after IOC. Skeleton validation will be performed during IOC. TP will be available for Cycle 2, however, a skeleton version must be tested and validated in

IOC. IOC AOT testing requires validation of all modes of operation and operating parameters over a broad range. There are approximately 80 to 100 parameter selections or specifications available to the observer. Data processing pipeline must undergo full operational testing for the Ph/SR and Scan AOTs, and skeleton testing for the SED and TP AOTs.

4.23.4 Preliminary Calibration

Preliminary calibration activities include production of pipeline-quality flat fields, calibration of stimulators against celestial sources, SED mode wavelength calibration, and spectral leak checks.

4.23.5 Routine Calibration Activities

Warm-up activities are scheduled at the beginning of every campaign, including turn-on/warm-up, detector anneals, and Vrst optimization. Dark frames, flat fields, and flux standards are taken once per campaign. Ge detector anneals are performed every 3 hours. Si detector anneals and stimulator flashes are performed once per day. Shut-down activities are scheduled at the end of every campaign, including Ge detector anneal, Vrst optimization, and transition to off.

4.23.6 Campaigns

Telescope thermal background requirements are particularly acute for MIPS. The 24 μm channel has the highest ambient background tolerance, so it can get a head start, before the focus adjustment. The 160 μm channel has the lowest ambient background requirement, and hence has the highest impact on the schedule-it must wait until after focus adjust to start. Tasks are broken into modular chunks, e.g., separate bands, to get an early start at 24 μm.

Some tasks have dependencies, e.g., flat-fields are done before focal plane surveys or PSFs. Where appropriate, short trial runs of long tasks are executed early, to reduce risk of failure. Large tasks may be divided into smaller pieces in different campaigns. Campaigns are spaced to allow for data processing turn-around time where needed. Campaigns are designed to avoid overloading the principals at any one time.

5. FOCUS ASSESSMENT AND ADJUSTMENT PLAN

Focus assessment and adjustment is comprised of a set of activities that are distributed throughout the IOC period.

5.1 Pre-launch Focus Setting

Prior to launch, the predicted on-orbit telescope focus position is set during the CTA performance ground test. During the ground test, an internal artificial star illuminates the focal plane with the telescope in auto-collimation using a cryogenic test flat. The flight focus is set with the telescope and instrument at flight operating temperatures. The predicted flight focus setting includes position offset corrections due to cryogenic test flat curvature, the test source location, the aperture door window, double pass through the telescope, and gravity release.

5.2 On-orbit Focus Assessment

An overview of the focus assessment timeline is shown in Figure 3-3. IRAC takes images of selected stars at the initial IOC flight telescope focus position at first light, and every two days during cooldown to measure and monitor the telescope focus as the telescope cools. Ground analysis of IRAC images retrieve IOC focus position using specially designed image analysis tools. Similarly, the PCRS measures focus every two days as the telescope cools. IRS and MIPS take data in their short wavelength channels as soon as the thermal background permits. The results are compared with a set of pass/fail criteria, and presented to an evaluation committee, to decide whether or not to move the telescope focus, and if so, by how much. All 3 SIs and the PCRS have an opportunity to assess their image quality before the decision is made to adjust focus. Upon approval, the telescope focus mechanism is moved to the desired focus position.

Following the final focus move, each instrument, including the PCRS, takes a series of observations sufficient to confirm and accept the final focus position.

5.3 On-orbit Focus Adjustment

The focus adjustment activity is scheduled when the telescope reaches 25 K, where it is expected to be stable. The approach to focus adjustment is cautionary, to minimize risk in the operation of the mechanism in space. It is designed to minimize the amount of secondary movement that is executed. There is no planned focus sweep, i.e., to run the focus mechanism over a range of positions, taking images at each and choosing the best image and therefore the best focus position. Rather, the approach is based on a carefully verified optical model. A "family album" of model images is assembled for a range of focus and field of view positions. A set of IRAC images are compared to this family album, and the closest match indicates the amount and direction of the defocus.

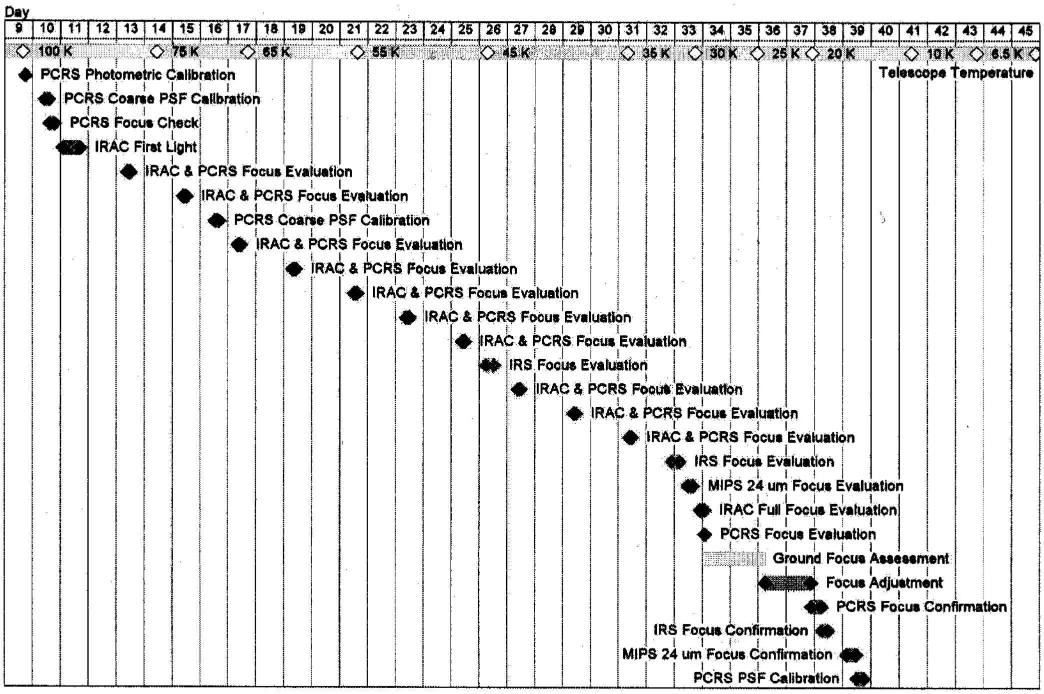

Figure 3-3: Focus assessment timeline

For the purposes of the nominal plan, it is assumed that the number of focus adjustments that will need to be made is 3. The case where more than 3 are needed is addressed by a contingency plan. The first focus move is planned to be a small exploratory move, meant to confirm the proper direction of the move has been executed, rather than to achieve ultimate focus. The second move is intended to reach the ultimate focus if the required secondary motion is less that 7 μm, or to undershoot by a small amount, 2 μm, if the required motion is larger. The third move is intended to achieve the ultimate focus if the previous move was intentionally undershot, or for some other reason failed to reach the ultimate focus goal. After each focus move, a set of IRAC images of a star are taken, to confirm the results of the move, and provide the data set from which the next focus mechanism step size is derived.

6. FOCAL PLANE SURVEY PLAN

The focal plane survey (FPS) is comprised of a set of activities that are distributed throughout the IOC and SV periods. The purpose of the focal plane survey is to determine the mapping of celestial coordinates to pixel coordinates for each focal plane array. A diagram of the locations of the SI fields of view in the focal plane is shown in Figure 3-5.

The approach for the focal plane survey is to execute a series of coarse surveys for each array, followed by a series of fine surveys. The coarse surveys have relaxed requirements, so that they are not driven by the need to change focus or to have a stable, cold telescope, but they provide enough pointing capability to proceed with other early activities. Once the telescope is focused and the focal plane is stable, a series of fine surveys are executed. The fine surveys provide the ultimate pointing capability for each array. The coarse survey and fine survey strategies and procedures are similar, except that the coarse surveys typically require fewer iterations. An overview of the FPS activity timeline is shown in Figure 3-6.

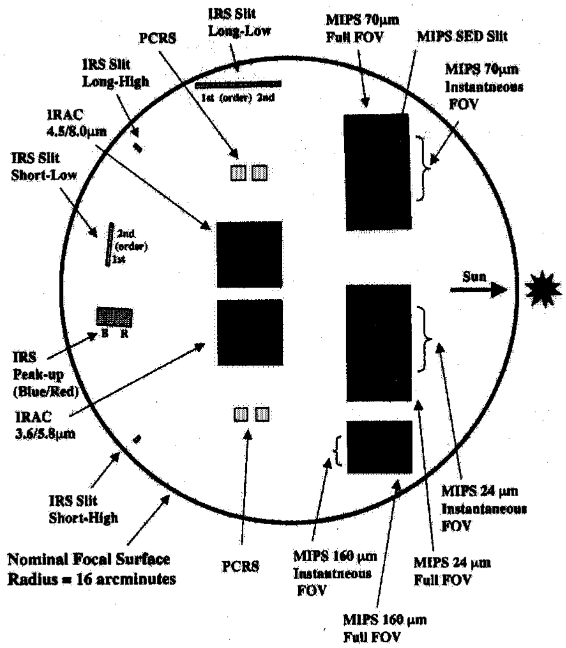

Figure 3-5: Focal plane field of view locations projected onto the sky

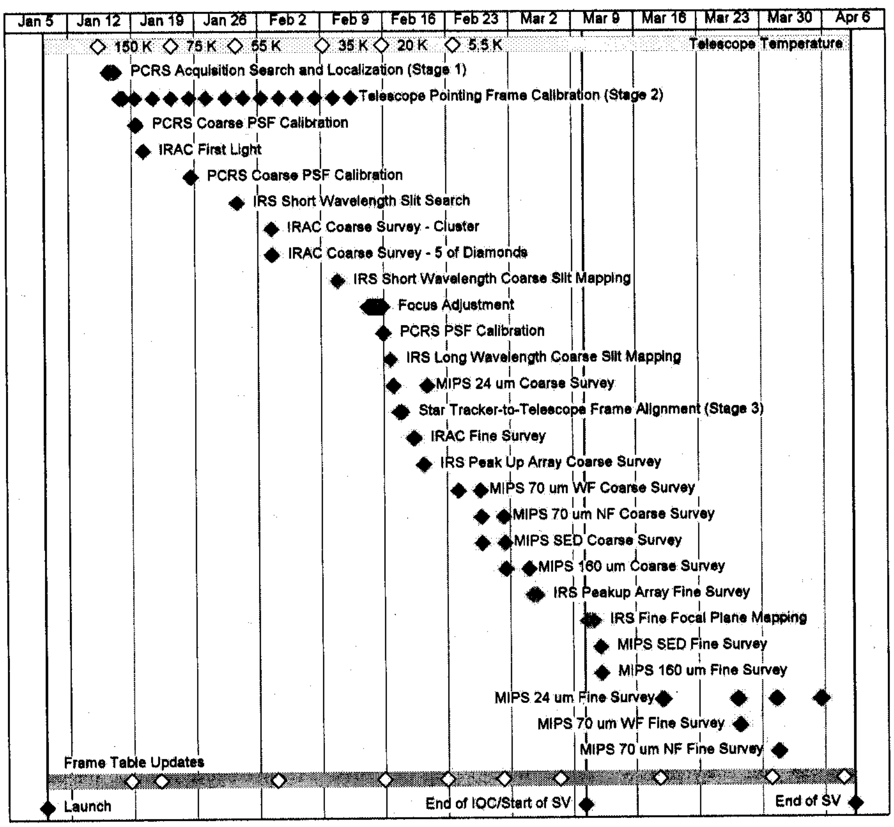

Figure 3-6: Focal plane survey timeline

6.1.1 Imaging Array Surveys

The typical survey maneuver for the imaging arrays is shown in Figure 3-14. The telescope is pointed to bring a star onto the PCRS-1 array. The PCS mode is set to gyros only, and then the telescope is repointed to bring the star onto the PCRS-2 array. The centroids reported from these two pointings determine the TPF. The star is then offset to five successive pointings on the array being surveyed, in a "5-of-diamonds" pattern. The 5 centroids yield information on the location, orientation, scale, and distortion of the array. The star is then brought back to the PCRS-1 array, which allows a correction for the linear gyro drift throughout the maneuver. Image centroid and timing information from the SI is collected along with PCS telemetry, and correlated via an instrument pointing frame filter that derives the location of the SI frame relative to the TPF.

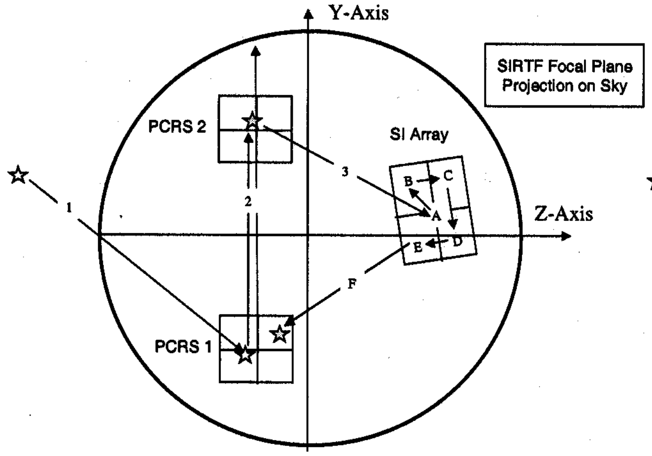

Figure 3-14: Imaging array prototype survey maneuver

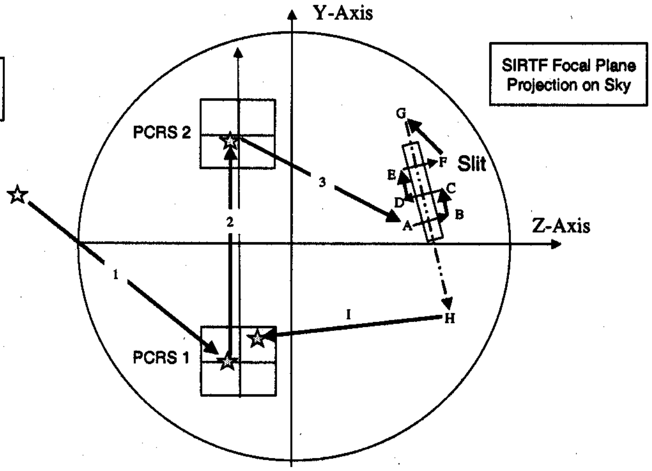

Figure 3-16: Slit scan prototype survey maneuver

6.1.2 Spectroscopic Slit Surveys

The typical survey maneuver for spectroscopic slits is shown in Figure 3-16. The telescope is pointed to bring a star onto the PCRS-1 array. The PCS mode is set to gyros only, and then the telescope is repointed to bring the star onto the PCRS-2 array, to determine the TPF. The star is then offset to the slit, and slit scans are executed, back and forth, in the dispersion direction of the slit. After the last cross-slit scan, a final scan is executed along the length of the slit and down the middle, to find the ends of the slit. The star is then brought back to the PCRS-1 array, to correct for the linear gyro drift. Slit crossing times are collected along with PCS telemetry, and correlated via an instrument pointing frame filter that derives the location of the SI frame relative to the TPF. This information is uploaded to an onboard frame table.

7. CONCLUSION

The IOC/SV plan is an aggressive program to bring SIRTF online within programmatic constraints, yet it is built with an approach that mitigates risk to the schedule, and provides the necessary data calibrations and characterizations to make effective use of the observatory as soon as the primary science mission begins 90 days after launch.